Comparison of two different measurement methods to determine glenoid bone defects: area or width?

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Background: This study compared two different techniques that have been used to measure the glenoids of patients with recurrent anterior shoulder dislocation.

Methods: We analyzed 36 patients who had received arthroscopic Bankart repair for anterior shoulder instability. Retrospectively, 3-dimensional computed tomography images of both shoulders were available for these patients. Two measurement methods were compared to determine the glenoid defects. One of these techniques is based on linear measurement, previously defined as the glenoid index. The other method is based on surface area measurement. Subsequently, 3 more diameters and the average values obtained from these diameters were compared with the surface measurement method. Pearson correlation coefficient ($r$) was assessed to determine the relationship.

Results: There was an almost perfect relationship between measurement methods when the defect area was less than 6\% of the inferior glenoid circle ($r$, 0.915; $P < .001$). This relation decreased and the difference became more pronounced ($r$, 0.343; $P = .657$) when the bone loss exceeded 14\% of the inferior glenoid circle. The highest correlations with the actual defects were the average values obtained from 4 different diameters ($r$, 0.964; $P < .001$) and the 4-o’clock position of the single diameter measurements ($r$, 0.860; $P = .001$). In addition, 11 patients had crescent-like defects, demonstrating a relatively low correlation between the measurement methods ($r$, 0.679; $P = .021$).

Conclusion: Although the best correlation was achieved from average values obtained from different diameter positions, in practical use, we advise a linear measurement to estimate the glenoid bone loss at the 4-o’clock position to achieve a high correlation between the measurement techniques.

Level of evidence: Level III, Diagnostic Study.

Keywords: Glenoid bone loss; instability; glenoid index; arthroscopy; shoulder; Pico method

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Several factors affect the stability of the glenohumeral joint. One of the most important factors is the bone integrity of the glenoid. Traumatic glenohumeral dislocation may lead to a fracture of the anterior-anteroinferior part of...
the glenoid, ranging from an impression fracture to significant bone loss of the glenoid surface, which can result in an inverted pear-shaped glenoid.\textsuperscript{6,23} The prevalence of this defect may be up to 90% of patients with anterior instability.\textsuperscript{24} Further, Burkhart et al\textsuperscript{6} have shown that significant glenoid bone loss negatively affects the success rate of arthroscopic repairs of anterior instability. Therefore, a preoperative assessment of bone loss including a defect’s location and precise size is crucial as a notable loss of bone leads to a higher failure rate after arthroscopic repair.

The method of quantification should be accurate and reliable. Several methods have been described to measure the size of glenoid bone defects and are based on either linear\textsuperscript{2,7,8,12,18,21} or surface area measurement\textsuperscript{3,20,24}; however, no consensus has been reached to date. Linear measurements are mostly based on the width of the inferior glenoid circle, and surface measurements quantify the defective area as a percentage of the inferior glenoid circle. We hypothesized that two different measurement techniques do not differ in determining glenoid bone defects. Whatever the measurement method, computed tomography (CT) has been the current standard imaging modality to quantify glenoid bone loss.\textsuperscript{5,22}

We conducted a retrospective study of the glenoids of 36 patients with recurrent anterior shoulder dislocation. The purpose of this study was to analyze and compare the correlation between the surface measurement technique and a linear measurement method (glenoid index\textsuperscript{8}). The second purpose of our study was to show the best correlation between the surface measurement method and the linear technique at different positions.

**Methods**

The primary criteria for inclusion in this study were patients who had traumatic, unilateral, recurrent shoulder instability with a minimum of 2 episodes of dislocation and who had received an arthroscopic Bankart repair for anterior instability. Exclusion criteria were patients who had any previous bone reconstruction of the glenoid, any previously failed instability repair, and bilateral involvement.

This retrospective study evaluated the patients between April 2007 and May 2012; 36 patients (36 shoulders) met these criteria. Humeral head subtracted 3-dimensional (3D) CT images of both the injured and intact shoulders (en face view) were available for these patients. The images were analyzed by a software program (AutoCAD, version 2008; Autodesk, San Rafael, CA, USA). All of the measurement parameters were independently measured by 3 independent reviewers who were experienced in shoulder surgery, and each observer was unaware of the other observers’ results.

In light of the study of De Wilde et al\textsuperscript{10} it was hypothesized that the glenoids of the same patients would not differ substantially. Therefore, contralateral normal shoulder images were used for comparison of the involved sides (Fig. 1, A), and we compared 2 measurement techniques with the opposite unaffected shoulder glenoid. For the first measurement technique, surface measurements were performed on the en face view of 3D CT images, as suggested by Baudi et al\textsuperscript{1}, using the Pico method, which was originally based on 2-dimensional CT scans. We used the best fitting circle on the inferior glenoid of the contralateral side, and an identical circle was drawn on the affected glenoid to define the center and radius of the inferior glenoid circle. An osseous defect at the anterior and anteroinferior quadrant of the glenoid rim was confirmed and marked freehand. The missing part of the glenoid (defective area, DA) and the whole area of the circle (W) were precisely measured with the software, and a ratio was expressed representing the percentage of the defective area (surface DA/surface W × 100) (Fig. 1, B).

The second measurement technique determines the glenoid bone loss as a linear measurement of the missing bone by using basic proportions between glenoid height and width in the normal and affected shoulder (Fig. 2, A). Chuang et al\textsuperscript{8} introduced this measurement technique and termed it the glenoid index. We converted the glenoid index as a percentage of the linear bone loss to avoid confusion and to achieve direct correlation between the measurement methods (i.e., glenoid index of 0.850 represents a linear bone loss of 15% of the diameter). In addition, we defined and used 4 different diameters at the 2-o’clock (D2), 3-o’clock (D3), 4-o’clock (D4), and 5-o’clock (D5) positions to correlate with the area measurement (Fig. 2, B). Subsequently, to investigate which combination of the diameters was highly correlated with the other measurement technique, 11 more values were obtained by averaging the values of different diameter combinations: D2-D3 (A2-3), D2-D4 (A2-4), D2-D5 (A2-5), D3-D4 (A3-4), D3-D5 (A3-5), D4-D5 (A4-5), D2-D3-D4 (A2-3-4), D2-D3-D5 (A2-3-5), D2-D4-D5 (A2-4-5), D3-D4-D5 (A3-4-5), D2-D3-D4-D5 (A2-3-4-5). The same software was used for all measurement techniques to calculate the glenoid bone defects on en face views of the images.

**Statistical analysis**

Statistical analyses were performed with SPSS software (version 17.0; SPSS Inc, Chicago, IL, USA). The concordance correlation coefficient between 3 observers for each measurement and the multivariate agreement coefficient among observers were used to assess the interobserver reliability. Intraobserver reliability of the 2 measurement methods was assessed with the intraclass correlation coefficient (ICC). Each measurement was performed on 2 separate occasions by each observer and 2 weeks elapsed between the observations. Because the comparison of the evaluators showed similar results, mean values were used to compare the relationship between the measurement methods. Pearson correlation was performed to determine the relationship of the measurement techniques between normally distributed variables, and Spearman correlation coefficient was calculated between non-normally distributed variables. The strength of the relationship was classified\textsuperscript{11} as strong ($r > 0.5$), medium ($0.3 < r < 0.5$), small ($0.1 < r < 0.3$), or none ($r < 0.1$). The strength of the agreement was classified\textsuperscript{11} excellent (ICC > 0.75), good (0.40 < ICC < 0.75), or poor (ICC < 0.40). The level of significance was accepted as .05.

**Results**

Distribution of the glenoid defects indicated that 6 patients exhibited isolated bone loss either above or below the 3-o’clock position but not extending to the 3-o’clock position.
According to the surface measurement technique, all patients (100%) had glenoid bone defects; however, 6 patients (16.6%) had no bone defects according to the glenoid index but instead had defects at different positions of up to 8.3% of the total diameter. The mean glenoid bone loss was 7.55% (range, 1.2%-21.8%) of the inferior glenoid circle area, and the mean missing part at the 3-o’clock position was measured as 9.5% (range, 0%-17.8%) of the diameter.

In our patient group, we used 4 different diameters of the inferior glenoid circle at the 2-o’clock, 3-o’clock, 4-o’clock, and 5-o’clock (D2, D3, D4, D5) positions to establish the best correlation with area measurement. Bone defects at each position were calculated as a ratio and correlated with the spatial measurement technique. Overall, including all 36 glenoids, the best correlation with the surface measurements was D4 \( (r, 0.875; P < .001) \), followed by D3 \( (r, 0.870; P < .001) \) (Table I).

The defective area was classified into 3 groups (<6%, 6%-14%, >14%) by use of the hierarchical cluster analysis method in the SPSS program. If the defective surface area measured with the surface technique was less than 6%, the relationship was almost perfect as the Pearson correlation coefficient became 0.915 \( (P < .001) \). However, if the defective area was higher than 14% of the inferior glenoid circle, the measurements presented a medium relationship and the Pearson correlation coefficient was decreased to 0.343 \( (P = .657) \) (Table II).

When all the en face views for each patient were evaluated, morphologic assessment revealed that a subgroup of patients presented with a biconcave distribution of glenoid defects leading to ellipsoidal or kidney-shaped glenoids (Fig. 3). These patients had smaller percentages of linear glenoid bone loss when it was measured at the 3-o’clock position, but they actually had larger glenoid defects according to the surface area measurement, or vice versa (Fig. 3). These 11 glenoids (30.5%) presented 2 distinctly separate regions of defective areas; one extended up to the 2-o’clock position, and the second region extended through

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**Figure 1** The best fitting virtual inferior glenoid circle was created on the unaffected side (A), and an identical circle was drawn on the affected glenoid (B). The defective area was marked for surface measurement (B). The shaded area represents the defective area (DA), and a ratio was expressed with the formula \( \text{surface DA/surface W} \times 100 \).

**Figure 2** The reference points were labeled on the uninvolved glenoid (A). A line was drawn between the base of the coracoid and the most inferior aspect of the glenoid. Thus, the maximal glenoid height was determined (white line). This line was moved to the involved glenoid and used for adjustment. The second line was drawn perpendicular to the maximal glenoid height at the widest portion of the inferior glenoid for the glenoid index measurement technique (black line). In addition, 4 different diameters were marked at the 2-o’clock \( (D_2) \), 3-o’clock \( (D_3) \), 4-o’clock \( (D_4) \), and 5-o’clock \( (D_5) \) positions (B).
Table I  Correlation between measurement methods for all patients

<table>
<thead>
<tr>
<th></th>
<th>D_2</th>
<th>D_3</th>
<th>D_4</th>
<th>D_5</th>
<th>A2-3-4-5</th>
<th>A2-4-5</th>
<th>A2-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>All patients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r</td>
<td>0.777^,*</td>
<td>0.870^,*</td>
<td>0.875^,*</td>
<td>0.580^,*</td>
<td>0.964^,*</td>
<td>0.940^,*</td>
<td>0.940^,*</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>N</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

The correlation between the 2 measurement methods was demonstrated for all patients at different positions and average values were obtained from different diameters.

* Statistically significant at .05 for 2-way correlation.
† Statistically significant at .01 for 2-way correlation.
‡ Spearman correlation was determined. In other situations, Pearson correlation was calculated.

Table II  Correlation between surface area and diameter measurement at the 3-o’clock position (glenoid index)

<table>
<thead>
<tr>
<th>Area</th>
<th>Width</th>
<th>D_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6.0</td>
<td>r = 0.915^,*; P &lt; .001</td>
<td></td>
</tr>
<tr>
<td>6.1-14.0</td>
<td>r = 0.494^,*; P = .032</td>
<td></td>
</tr>
<tr>
<td>&gt;14.1</td>
<td>r = 0.343^,*; P = .657</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>r = 0.869^,*; P &lt; .001</td>
<td></td>
</tr>
</tbody>
</table>

* Pearson correlation coefficient.

the 6-o’clock position, creating a spike just at the 3-o’clock position (Fig. 3, A). These glenoids can be identified as having much more bone loss at the 2-o’clock or 4-o’clock position than at the 3-o’clock position in terms of diameter measurements. In gross appearance, these defects may also demonstrate a crescent-like image (Fig. 4).

When we evaluated these 11 patients with biconcave defects, the average values of different positions were still highly correlated (r for A2-3-4-5, 0.924; r for A2-4-5, 0.898; r for A2-4, 0.859) with the actual defects; however, the results showed a moderate correlation for D_3 (r, 0.679; P = .021) and a substantial decrease for D_4 (r, 0.433; P = .183) (Table III). As a single diameter measurement, D_4 has a relatively high correlation coefficient with the area measurement (r for D_4, 0.860; P = .001) (Table III).

A comparison of the evaluators showed similar results, and the pairwise and overall agreement among evaluators showed excellent concordance correlation coefficients (P < .001) between 2 observers for each measurement. The multivariate agreement coefficient among observers for 2 measurements was 0.926 (Table IV). For the intraobserver reliability of the measurement, physicians’ agreement between their observations showed excellent ICCs for each measurement method (Table V).

According to our results, in both the group of patients with biconcave defective glenoids and the entire group of patients as a whole, we found that the best correlation with area measurement is the average value obtained from diameters at the 2-o’clock, 3-o’clock, 4-o’clock, and 5-o’clock positions (A2-3-4-5). More important, D_4 demonstrates the best correlation for the single diameter measurements for both patient groups (Tables I and III).

Discussion

Studies have shown that the size of the glenoid defect directly affects stability of the shoulder. These bone lesions must be correctly located and quantified for selection of the proper surgical method without underestimation or overestimation of the bone loss. Therefore, the difficulty is in determining the size of the bone loss to decide between the different operative treatment options.

The most important finding of this study was that defects of less than 6% of the surface area represent a critical interval in which almost perfect correlation between the glenoid index and the surface measurement method is achieved. This means that both measurement methods estimate smaller defects with high concordance. However, when the defective area exceeded 14% of the surface area, the correlation decreased substantially. It is obvious from our study that as the defect size increases, the correlation decreases. Thus, measurement techniques referencing the 3-o’clock position may present misleading ratios of bone loss for larger defects, which is important for the decision-making process for severe glenoid defects necessitating a bone graft.

In our study, we noticed that one group of patients demonstrated a nonuniform (biconcave) distribution of their glenoid defects. In this patient group, a notable part of the defective area was found between the 2-o’clock and 3-o’clock positions with an accompanying lesion between the 3-o’clock and 4-o’clock positions but...
relatively less bone loss at the 3-o’clock position. These kinds of defects represent less bone loss at the 3-o’clock position but larger overall defects (Fig. 3, A). This exceptional situation led us to investigate the differences between 2 measurement methods. Thus, we found that the correlation between the linear and surface measurement techniques substantially decreases in this patient group and a high correlation still exists at the D4 position.

Another important point is the variable location of the most defective region of the glenoid. As reported by Griffith et al13 and Saito et al,23 bony Bankart defects can extend superiorly over the 3-o’clock position and inferiorly over the 6-o’clock position. To define the most common location of glenoid bone defects, Ji et al15 demonstrated in their model that the 3:20-o’clock position is the most common location of glenoid defects in shoulder instability. Moreover, our study demonstrated the variable position of glenoid defects. In our patient group, 6 patients (16.6%) had no defects extending to the 3-o’clock position but had defects at different positions. These patients may manifest their actual bone loss with the surface measurement technique or by calculation of the average of linear measurements from different diameters.

On the basis of these facts, we investigated whether there is any correlation between area and linear measurements, considering the variable position of glenoid defects. According to the present study, measurements from a single diameter are less strongly correlated than average values of multiple diameter measurements. However, averaging of multiple diameter measurements may not be practical in use. Because of its high correlation with the surface area measurement method, the 4-o’clock position (D4) should be considered for an accurate measurement rather than the other investigated positions (D2, D3, D5), although the r coefficient of D3 was very close to the r coefficient of D4. However, this difference increased only when the patients with biconcave or crescent-like deficits were considered.

To date, various authors have introduced different measurement methods to present glenoid bone defects quantitatively. Some such techniques2,7,8,12,18,21 were based on the diameter of the inferior glenoid circle, and others were based on the surface of the defective area.3,5,20 This study aimed to determine whether there is any correlation between area and diameter measurement techniques, considering the variable
position of the defects and different measurement locations (diameters). We used real bone defects in actual patients, rather than creating defects in cadaver or bone models. We identified that the real bone defects actually occurred in heterogeneous shapes and variable positions, which is different from the defects that were created in straight and smooth shapes in cadaver or bone models. This may have led to inaccurate results when the linear measurement techniques were applied.

Burkhart et al7 reported the use of the bare spot as a reference point for the intraoperative arthroscopic assessment of the glenoid surface and suggested an arthroscopic reference of 25% for bone defects (inverted pear shape). However, in time, Kralinger et al16 showed that the bare spot was not located exactly at the center of the inferior glenoid, and Aigner et al1 reported that it is located eccentrically in most shoulders and cannot always be well visualized during surgery. Therefore, bone loss measurement by the bare spot method can overestimate the area of the missing glenoid, leading to the inadequate measurement of bone loss.21 Lo et al16 have noted that the inverted pear-shaped glenoid represents a significant amount of bone loss, at least 25% to 27% of the width of the inferior glenoid, and proposed a bone reconstruction procedure. Itoi et al15 showed that a defect of 21% of the glenoid width might cause instability and stated that this type of glenoid creates an unstable condition and is prone to redislocation after an arthroscopic Bankart repair. In addition, Bigliani et al1 recommended coracoid transfer if the glenoid rim fracture represents more than 25% of the anterior-posterior diameter of the glenoid because of the high recurrence rates. As a summary of the previous studies, Chuang et al3 introduced a measurement technique based on diameter measurements called the glenoid index. Described studies were based on either arthroscopic measurements or 3D CT scan views with use of linear measurements.

In contrast to these linear measurements, Sugaya et al24 evaluated the CT scans of patients with recurrent anterior glenohumeral instability and quantified the area of the detached osseous fragments (osseous Bankart lesions). The authors found glenoid rim lesions present in 90% of their patient group. Baudi et al3 developed a CT method and introduced the Pico method to precisely detect and to measure bone defects in terms of their area and percentage (glenoid index).

Table III: Correlation between measurement methods for patients with biconcave defects

<table>
<thead>
<tr>
<th>Patients with biconcave or crescent-like defects</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>A2-3-4-5</th>
<th>A2-4-5</th>
<th>A2-4</th>
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<tbody>
<tr>
<td>r</td>
<td>0.433</td>
<td>0.679</td>
<td>0.860</td>
<td>0.705</td>
<td>0.924</td>
<td>0.898</td>
<td>0.859</td>
</tr>
<tr>
<td>P value</td>
<td>.183</td>
<td>.021</td>
<td>.001</td>
<td>.015</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>.001</td>
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<tr>
<td>N</td>
<td>11</td>
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<td>11</td>
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<td>11</td>
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</tbody>
</table>

Table IV: Interobserver agreement for each measurement method

<table>
<thead>
<tr>
<th>Patients with biconcave or crescent-like defects</th>
<th>r</th>
<th>P value</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>0.830</td>
<td>.007</td>
<td>11</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>11</td>
</tr>
<tr>
<td>N</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

Biconcave defects were correlated with diameters at different positions and average values were obtained from different diameters.

Pearson correlation was determined in all situations.

Statistically significant at .05 for 2-way correlation.

Statistically significant at .01 for 2-way correlation.

Table IV: Interobserver agreement for each measurement method

<table>
<thead>
<tr>
<th>Surface area measurement</th>
<th>Linear measurement (glenoid index)</th>
<th>Pairwise and overall agreement</th>
</tr>
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<tbody>
<tr>
<td>f22</td>
<td>0.920</td>
<td>0.913</td>
</tr>
<tr>
<td>f23</td>
<td>0.940</td>
<td>0.923</td>
</tr>
<tr>
<td>f23</td>
<td>0.925</td>
<td>0.935</td>
</tr>
<tr>
<td>Iota</td>
<td>0.926</td>
<td></td>
</tr>
</tbody>
</table>

* Concordance correlation coefficient between 2 observers for each measurement.

† Multivariate agreement coefficient among observers for 2 measurements.
results, we found that the best correlation with the area measurement is the $A_{2.3-4.5}$. Thus, the ideal method to determine the defective area seems to be use of average values obtained from different diameter positions because of the nonuniform distribution of the bone loss. Among single diameter measurements, $D_4$ showed the best correlation with the actual surface defects, followed by $D_3$ (Table I).

Our study showed that the correlation decreases as the defect gets larger, especially for the patients with biconcave defects. Interpretation of our results is important in terms of quantifying and determining the extent of a glenoid bone defect, and surgeons should consider this in deciding on anchor configurations during arthroscopic Bankart repairs or proper placement of bone grafts during bone block procedures. In a retrospective study, the position of the bone grafts on the glenoid was found in the zone of 2:30-4:20 hours. Therefore, it is possible to appropriately consider the patients preoperatively and to individualize the location of anchors and the position of bone grafts for the patients with biconcave defects. This may be possible by use of the surface area measurement technique or by use of the 4-o’clock position because of its high correlation with the surface measurement technique. Also, preoperative assessment with both methods may help individualize treatment in cases in which we cannot decide on bone block procedures or arthroscopic techniques.

One limitation of this study is that patients who were undergoing arthroscopic Bankart repair were selected; thus, patients who have much more bone loss were excluded. Inclusion of patients with larger bone defects might affect the results of the correlation between the measurement techniques. Another limitation of our study is that measurements had to be made freehand because of the necessity of marking the boundaries of the defective area. Although this is a limitation, statistical results showed excellent intraobserver and interobserver reliability.

### Conclusions

We report that the correlation between the linear (glenoid index) and surface area measurement methods decreases as the bone defect gets larger. In our patient group, we demonstrated the heterogeneity of the bone defects, and 2 different measurement methods presented incompatible results. In deciding on treatment method, this mismatch must be considered. However, these limited recommendations do not apply for those patients with larger defects who were not considered candidates for arthroscopic stabilization. Although the best correlation was achieved from average values obtained from different diameter positions, in practical use, we advise a linear measurement to estimate the glenoid bone loss at the 4-o’clock position to achieve a high correlation between the measurement techniques.

### Disclaimer

The authors, their immediate families, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

### References


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**Table V** Results of glenoid bone loss measurements and intraobserver agreement by 2 independent observers based on the 2 different measurement methods

<table>
<thead>
<tr>
<th></th>
<th>SAMM First evaluation (%)</th>
<th>Second evaluation (%)</th>
<th>LMM First evaluation (3-o’clock position)</th>
<th>Second evaluation (3-o’clock position)</th>
<th>ICC Intraobserver agreement for SAMM</th>
<th>ICC Intraobserver agreement for LMM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer 1</td>
<td>7.7 ± 3.2</td>
<td>7.4 ± 2.5</td>
<td>9.5 ± 2.0</td>
<td>9.3 ± 3.3</td>
<td>0.88</td>
<td>0.86</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Observer 2</td>
<td>7.5 ± 2.2</td>
<td>7.6 ± 3.0</td>
<td>9.3 ± 2.4</td>
<td>9.6 ± 3.9</td>
<td>0.94</td>
<td>0.91</td>
<td>&lt;.001</td>
</tr>
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</table>

*ICC,* intraclass correlation coefficient; *LMM,* linear measurement method (glenoid index); *SAMM,* surface area measurement method.


